The 9th European Congress on Computational Methods in Applied Sciences and Engineering
ECCOMAS Congress 2024
3 – 7 June 2024, Lisboa, Portugal

# FLEET AND TRAFFIC MANAGEMENT SYSTEMS FOR CONDUCTING FUTURE COOPERATIVE MOBILITY

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**Key words:** transport engineering, traffic management, fleet management.

**Summary.** As urbanisation continues to increase worldwide, cities face the challenge of accommodating growing populations while maintaining efficient and sustainable transportation systems. The integration of connected and autonomous vehicles is key to transforming urban mobility. This paper outlines the Horizon Europe project CONDUCTOR, which explores innovations in traffic and fleet management to optimise the transport of people and goods. Using AI-supported simulation models and tools, the project aims to improve the capabilities of transport authorities in Europe. Expected outcomes include reduced traffic delays, shorter travel times and better public transport experiences, ultimately leading to smoother urban transportation and a higher quality of life.

## 1 INTRODUCTION

The project *Fleet and traffic management systems for conducting future cooperative mobility* (CONDUCTOR) [1] is designing, integrating and demonstrating innovative traffic and fleet management concepts for improved passengers and goods transport, taking into account the integration of Cooperative, Connected and Automated Mobility (CCAM) vehicles into the mobility ecosystem. The proposed solution consists of a variety of advanced traffic management models and relevant scenarios ensuring seamless multimodality and interoperability. Dynamic balancing and priority-based management of vehicles are implemented with next-generation simulation tools enabled by machine learning and data fusion techniques. All innovative models and technologies developed within the CONDUCTOR project are aligned with future mobility needs thanks to a continuous discussion with stakeholders, including transport authorities and operators. Furthermore, these models are integrated and deployed within a customised platform that generates advanced simulations and compare the results with the current systems and solutions deployed within three Uses Cases (UCs) and their five Pilots.

## 2 USE CASES AND THEIR REQUIREMENTS

The functionalities developed within the CONDUCTOR project as a result of the model integration are validated by UC pilots. The UCs have been developed to demonstrate and evaluate the capabilities of the proposed future mobility system. Each UC addresses different aspects of the interoperability of traffic management systems and the integration of different transport modes, focussing on both passenger and freight transport. Specifically, UC1 considers integrated traffic management, UC2 focuses on demand-responsive transport and UC3 addresses urban logistics. These UCs are demonstrated in five pilots across Europe, each testing specific project functionalities using real data [2, 3].

### 2.1 Integrated Traffic Management and Inter-modality

UC1 (Integrated Traffic Management and Inter-modality) demonstrates activities in three cities: Athens (Greece), Madrid (Spain), and Almelo (the Netherlands), showcasing novel traffic management strategies (including dedicated lanes, priority at intersections and more) for CCAM under real traffic conditions.

**Athens**: the UC1-Athens pilot focuses on the synchronization of buses and on-demand services with the metro and tram systems (see Figure 1). This is achieved by adjusting their schedules to reduce door-to-door travel times for passengers. In addition, novel traffic management strategies for CCAM are being implemented. Key strategies include AI-assisted control of traffic signals for multimodal traffic, strategies for the allocation of road space and the integration of transit fleets into traffic management systems. It also emphasises rescheduling and rebalancing strategies to improve overall efficiency.

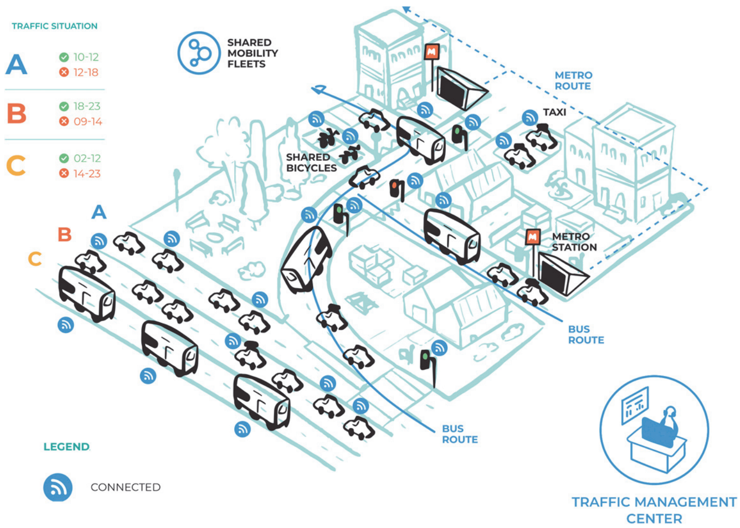


**Figure 1** UC1-Athens pilot

When analysing this scenario, we identified four important stakeholder categories: transport operators, travellers, traffic managers and local public administrations. We analysed their objectives for the proposed solution and assessed the benefits and drawbacks in relation to the social and regulatory requirements set by EU policy for CCAM. The perspectives and expectations of each group are summarised in Table 1 and Table 2.

**Table 1** Key considerations of transport operators, traffic operators, public administrations and passengers

| Transport operators | Traffic management operators | Local public administrations | Travel passengers |
|---|---|---|---|
| The main purposes include | | | |
| To cut costs of the operations with an overall improvement of the service and higher satisfaction and loyalty of passengers | To improve operations efficiency and reduction of costs | The better achieve local, national and EU mobility goals (environmental, social and economic sustainability connected to mobility) | To have accessible mobility (prices) and optimal ways to get their destinations |
| The expected benefits envisage | | | |
| Reduction in costs and congestion | Reduction in congestion | The better achieve mobility goals (environmental, social and economic sustainability connected to mobility) | A reduction of travel time, having a more reliable and accessible |
| The possible drawbacks may concern | | | |
| The high investments and the effects that this automation may have on the reduced workforce strategies | The high investments and the management of complex situations with less space for private road users | The resistance of their communities to this innovation and the potential loss of consensus | Apparently, none |

**Table 2** Social and regulatory priorities of transport operators, traffic operators, administrations and passengers

| | | Transport operators | Traffic management operators | Local public administrations | Travel passengers |
|---|---|---|---|---|---|
| Social and regulatory priorities | Environment | X | X | X | |
| | Safety | | X | X | |
| | Accessibility | | | X | X |
| | Inclusiveness | X | | X | |
| | Wellbeing | X | | X | |

**Madrid**: the UC1-Madrid pilot focuses on the management of planned (e.g. road works) and unplanned (e.g. accidents) events to recover the normal operation of the transport network, with a focus on connected and autonomous vehicles (CAVs) (see Figure 2). Various scenarios are tested, including the use of specific routes and lanes for evacuation, prioritisation of emergency vehicles and control of access on the ring road. The use case also includes lane management and setting up alternative routes to avoid certain sections of the M-30 ring road.

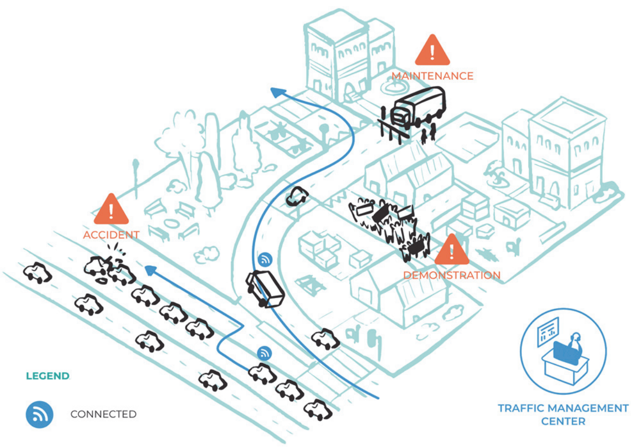


**Figure 2** UC1-Madrid pilot

**Table 3** Key considerations of passengers of CAVs, passengers of conventional cars, passengers of vehicles involved in the disruption, other network users and network managers

| Passengers of CAVs | Passengers of conventional cars | Passengers of vehicles involved in the disruption | Other network users | Network managers |
|---|---|---|---|---|
| The main purposes include | | | | |
| To arrive with minimum delay to the destination | To arrive with minimum delay to the destination | To arrive with minimum delay to the destination | To arrive with minimum delay to the destination | To recover the optimal state of the system in the minimum time |
| The expected benefits envisage | | | | |
| The access to optimal re-routing, reducing the impacts of delays and disruptions along journey | The reduction of travel time and delays minimizing the impact of disruption along their journey | The assistance and recovery from the accident/incident | Damped the effects of disruption and re-routing options on their normal journey | A faster system recovery, ensuring a better level of adherence to the system objectives (e.g. travel time) |
| The possible drawbacks may concern | | | | |
| The imposition to adopt sub-optimal routing options | Apparently, none | Apparently, none | To increase the travel time in their journey (even if not directly affected by disruption) | The systematic adaptation of infrastructures and traffic system management strategies (e.g. semaphoric coordination) |

**Table 4** Social and regulatory priorities of passengers of CAVs, passengers of normal cars, passengers of vehicles involved in the disruption, other network users and network managers

| | | Passengers of CAVs | Passengers of normal cars | Passengers of vehicles involved in the disruption | Other network users | Network managers |
|---|---|---|---|---|---|---|
| Social and regulatory priorities | Environment | | | | X | X |
| | Safety | X | X | X | X | X |
| | Accessibility | X | X | X | | X |
| | Inclusiveness | X | | | | X |
| | Wellbeing | | | | X | |

**Almelo:** the UC1-Almelo aims to improve traffic flow along an important logistics corridor by reducing the number of vehicles stopping at traffic lights. It includes a network-wide prioritisation of vehicles at signalised intersections to ensure a smooth flow of traffic. The aim is to support the authorities in the transition to net-zero emissions in transport and to increase public well-being.

In this scenario, we have identified three primary stakeholder categories: logistics operators, road authorities and general road users (including emergency services, cyclists, CAV users and public transport). We analysed their objectives for the proposed solution and weighed the benefits and drawbacks in terms of social and regulatory requirements. The perspectives and expectations of each group are summarised in Table 5 and Table 6 below.

**Table 5** Key considerations of logistic operators, road authorities and road users

| Logistic operators | Road authorities | Road users |
|---|---|---|
| The main purposes include | | |
| To improve the efficiency in delivering goods, optimising the costs of service | To improve the traffic flow, so ensuring a more accessible and liveable cities | To access to city businesses and activities in a reliable and safe way |
| The expected benefits envisage | | |
| Improving the service quality increasing the demand; ensuring the well-being of the employees and reducing delivery times and costs, fuel consumption and vehicles maintenance | Improving safety and reducing congestion and emissions exploiting at best the capacity of the infrastructures | Safer mobility by reducing the number of trucks in the city and reduce travel time and emissions, facilitating timely response to urban mobility needs |
| The possible drawbacks may concern | | |
| The adaptation of the purchase system and adequate training of employees and drivers. Moreover, the implementation could raise issues of privacy and reputational damages | The high investments and costs and may raise governance issues in terms of priorities and arbitration | Possible shortcomings in users' experience due to less predictable traffic signals, possible longer waiting time and longer travel time to exit city |

**Table 6** Social and regulatory priorities of logistic operators, road authorities and road users

| | | Logistic operators | Road authorities | Road users |
|---|---|---|---|---|
| Social and regulatory priorities | Environment | X | X | X |
| | Safety | | | X |
| | Accessibility | | | X |
| | Wellbeing | | X | X |

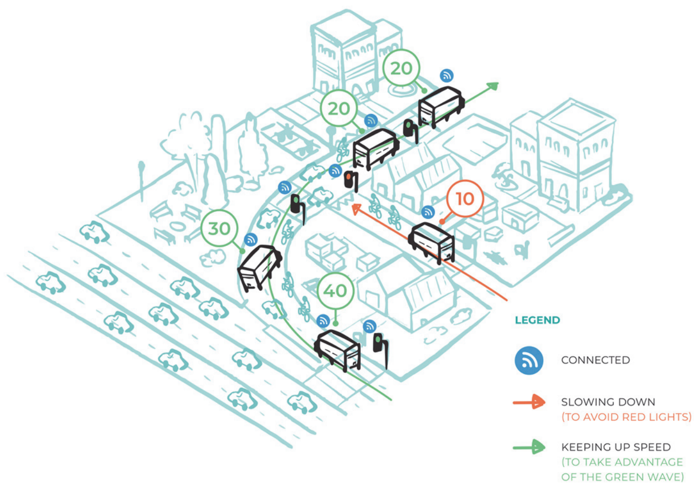


**Figure 3** UC1-Almelo pilot

## 2.2 Demand responsive transport

This UC involves a reservation-based shuttle service that provides an efficient and cost-effective transport solution for customers travelling long distances. The service includes stops to load and unload passengers as well as route deviations without compromising the system's ability to get customers to their destination on time.

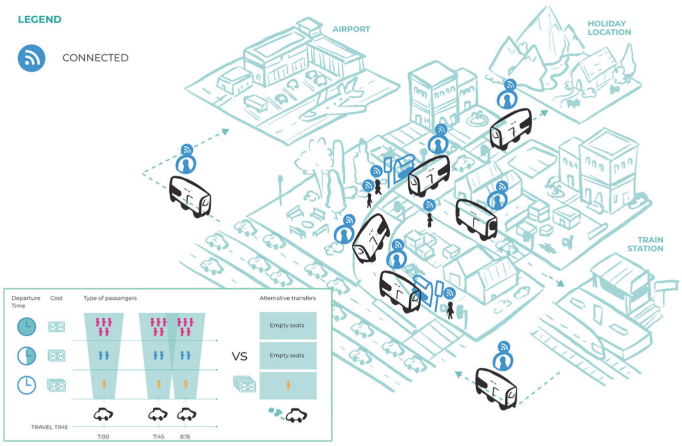


**Figure 4** UC2 Slovenia – Italy, Croatia, Austria

In this scenario, we have identified three primary stakeholder categories: passengers, drivers and operators. We have analysed their objectives for the proposed solution and weighed the benefits and drawbacks in terms of the social and regulatory requirements of EU policy for CCAM. The perspectives and expectations of each group are summarised in Table 7 and Table 8.

**Table 7** Key considerations of operators, drivers and passengers

| Operators | Drivers | Passengers |
|---|---|---|
| The main purposes include | | |
| To maximize the number of passengers in each shuttle | To know the exact location of the passengers and related pick-up points | To be transferred on time with minimal waiting time and to be timely informed |
| The expected benefits envisage | | |
| Hypothetically, the improvement in service quality and consolidation of passengers' loyalty | Hypothetically, better working conditions | To be delivered at the desired time with the cheaper transfer without using their own cars |
| The possible drawbacks may concern | | |
| The potential difficulties in adding new passengers in case of congestion | Apparently, none | Hypothetically, have an undue delay due to information gaps |

**Table 8** Social and regulatory priorities of operators, drivers and passengers

| | | Operators | Drivers | Passengers |
|---|---|---|---|---|
| Social and regulatory priorities | Environment | X | | |
| | Safety | X | | X |
| | Accessibility | | | X |
| | Inclusiveness | | | X |
| | Wellbeing | | X | X |

## 2.3 Urban logistics

This UC focuses on last-mile delivery solutions by integrating urban goods distribution with existing on-demand passenger transport services. Various strategies for passenger and freight coordination are explored, such as utilising the excess capacity of vehicles during periods of lower demand to facilitate last-mile urban parcel delivery while still prioritising passenger transportation.

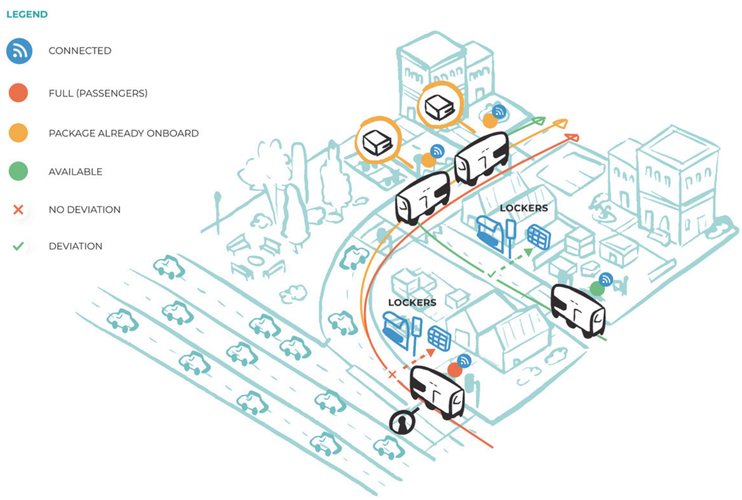


**Figure 5** UC3 Madrid

In this scenario, we have identified five important stakeholder categories: passengers, logistics companies, on-demand transport services, local residents and parcel recipients. We analysed their objectives for the proposed solution and assessed the benefits and drawbacks in light of the social and regulatory requirements set by EU policy for CCAM. The perspectives and expectations of each group are summarised in Table 9 and Table 10.

**Table 9** Key considerations of passengers, parcel receivers, residents, logistic companies and on-demand transport services

| Passengers | Parcel receivers | Local residents | Logistic companies | On-demand transport services |
|---|---|---|---|---|
| The main purposes include | | | | |
| To arrive on time without undue delays | To have cheaper delivery by an eco-friendly and on-time service | Minimal negative impacts and benefiting of the environmental, social and economic positive effects | To save on delivery costs, ensuring a cheaper and faster service with lower emissions | To make the public transport service more profitable |
| The expected benefits envisage | | | | |
| Apparently, none | Hypothetically, enjoy an eco-friendlier delivery service | The abatement of pollution, sound and traffic congestion | A cost-effective eco-friendly service with positive impacts on business image | An optimal use of vehicles capacity and a consequent optimisation of operations costs |
| The possible drawbacks may concern | | | | |
| Increased delays, degradation in comfortability, increased travel time and reduce safety | Increased delays | Increase delays; degradation in comfortability; increase travel time; reduce safety | Potential damages to parcels, lower delivery punctuality, contractual risks and customers' dissatisfaction | The management of more complex operations, lower punctuality, potential damages to vehicles and passengers' dissatisfaction |

**Table 10** Social and regulatory priorities of passengers, parcel receivers, local residents, logistic companies and on-demand transport services

| | | Passengers | Parcel receivers | Local residents | Logistic companies | On-demand services |
|---|---|---|---|---|---|---|
| Social and regulatory priorities | Environment | X | | X | X | X |
| | Safety | X | | X | | |
| | Wellbeing | X | X | X | X | X |

## 3 MODELS FOR ADAPTATION TO CCAM

To meet the requirements, the project develops and adapts models to support the transition to CCAM in order to improve the transport of passengers and goods. The models are tested in simulation environments and validated with real-world data. Objectives include adapting traffic and fleet management models, improving multimodality and interoperability, improving multi-resolution simulation models and developing governance models for future mobility systems. Several models have been developed and updated, such as for:

- Traffic management; e.g., Cooperative Traffic Management System (CTMS) and real-time traffic information for multi-purpose CCAM services,
- Fleet management; e.g., Pickup and Delivery Problem with Cross-dock for Perishable Goods (PDPCDPG) and real-time fleet management,
- Multimodality; e.g., a demand prediction method using a novel probabilistic transit assignment model and a multi-modal journey planning solution,
- Inter-operability; e.g., an agent-based interoperability framework,
- Multi-resolution simulation; e.g., simplified mesoscopic simulation model, Aimsun-FleetPy bridge for co-simulation and a calibrated traffic simulation model with real-world data to test coordinated traffic signal controls,
- Governance and regulatory models for CCAM services to maximise their potential.

The CTMS system was developed to transform urban simulation networks into adaptive multi-agent environments that enable testing of different multi-agent reinforcement learning strategies. This open-source tool, which is compatible with standard frameworks, has been successfully tested in the Athens network, in particular along Alexandras Avenue as part of UC1. In addition, real-time traffic information was integrated into the CCAM services. A co-simulation of FleetPy and Aimsun Next [4] with data from Munich demonstrates the importance of accurate travel time estimates for reliable CCAM performance [5, 6]. These achievements mark significant progress towards the goals of the project.

PDPCDPG optimises delivery costs by enabling connected vehicle cooperation, incorporating time constraints, and performing real-time route optimisation. Experimental results show that PDPCDPG can achieve global optimality within a reasonable time frame [7].

A novel probabilistic transit assignment model was developed and tested for demand prediction, as well as the design and initial implementation of a multimodal journey planning solution. Interfaces to Aimsun Next were created to replicate the network topology, integrate public transport data and use dynamic weights for the shortest path algorithms. In addition, a series of controllers were developed to emulate various mobility services, including station-based and free-floating bicycle and car sharing services.

An integration framework for multimodal simulation tools has been developed that incorporates fleet and traffic management models. Enhanced simulation tools, including Aimsun Next and Ride, have been further developed to improve traffic and fleet management. A simplified mesoscopic simulation model reduced calibration effort and the Aimsun Ride platform was enhanced for flexible fleet management testing. Relevant use cases include UC1-Athens, UC1-Madrid and UC3-Madrid. In addition, a framework for co-simulation of FleetPy and Aimsun Next was tested and a calibrated traffic simulation model for UC1-Almelo was created using real data to test coordinated traffic signal controls and conditional freight priority.

The governance and regulation of CCAM services were reviewed, focusing on stakeholder consultations, surveys on barriers to CAV adoption and data analysis to inform targeted actions for increasing CAV uptake. A hierarchical game-theory framework was developed to assess strategic interactions in traffic and fleet management. Analysis of 223 survey responses revealed that safety was the most important factor influencing Europeans' opinion of autonomous vehicles, with road infrastructure and appropriate legislation also being crucial [8, 9]. Economic accessibility was less important. This framework captures both stakeholder strategies and user responses to improve governance, policy and business models.

## 4 METHODS FOR SUPPORTING CCAM

The presented models are based on a robust data architecture for the optimisation of transport networks, particularly for mixed traffic involving both conventional and fully autonomous vehicles. The main objectives of the project include the selection and implementation of techniques for data gathering, harmonisation, fusion, analysis, dynamic network optimisation and anomaly detection. To achieve these goals, the project developed a comprehensive data architecture to support the models and algorithms, including the creation of smart data models and big data architectures compliant with FIWARE and IDSA standards. Key developments include the CONDUCTOR data space for data harmonisation, a space-time context graph for data fusion and analysis, and an ML-based fusion pipeline for detecting unusual traffic patterns during large-scale events. Optimisation techniques focus on network load balancing through centralised and decentralised CAV routing algorithms, a social rerouting framework that considers individual and situation-specific needs, and a dynamic optimisation model for Demand-Responsive Transport (DRT). In addition, anomaly detection was developed using various machine learning approaches to monitor transport supply and demand.

The application, improvement and development of data fusion techniques with the aim of generating important mobility-related information for CONDUCTOR's decision support models and tools. The aim is to convert harmonised, complementary data from different sources into mid- and high-level features used by these models [10]. This includes pattern recognition, data matching, enrichment, imputation and predictive modelling to map data of different granularity. The developed algorithms should support the creation of new optimisation, mobility and traffic models as well as represent observed behaviours and derive patterns for technical and environmental modelling in the UCs. Key solutions were identified based on the needs of the UCs, including:

- Characterisation and demand estimation of last-mile delivery trips using geolocalised data and surveys.
- Estimating demand for shared mobility as an indicator of CCAM adoption.
- Enrichment of user profiles with car ownership and home size features.
- Space-time context and data fusion methods to integrate heterogeneous sources.
- Identification of unusual traffic patterns based on major events to predict traffic hotspots and support transportation planning.
- Development of a smartphone-based data analysis framework for processing and analysing sensor data.
- Data manipulation techniques to improve the simulation capabilities of FleetPy through Aimsun co-simulation.

The algorithms, which are tailored to the specific needs of UCs, are designed to be adaptable, allowing general methodologies to be applied to other cases with similar data characteristics.

Solutions have been developed for dynamic optimisation and load balancing of transport networks, with a focus on routing and demand balancing for fleets of CAVs [11]. This includes both centralised and decentralised CAV routing algorithms: The centralised scheme manages routing requests before the start of the trip, while the decentralised hierarchical control scheme provides flexibility for rerouting during trips. In addition, a framework for social rerouting as a travel demand management measure was created and tested in a public transport system. An efficiency increases of up to 25% was observed when 20% of travellers behaved socially. The evaluation of the prediction models shows that some already exceed the baseline forecasts. Co-simulation studies conducted by TUM for Munich underline the crucial role of efficient routing for DRT vehicles to avoid significant delays and schedule adjustments. Co-simulation studies for Munich underline the importance of efficient routing for DRT vehicles to avoid significant delays and timetable adjustments. The requirements for multimodal traffic signal control for the target groups were also determined.

Another important focus is the detection of anomalies, i.e. the development of models to detect unusual patterns in transport supply and demand [12]. This includes the use of statistical, machine learning and deep learning approaches to detect anomalies and improve the overall performance of the transport network. The project made significant progress in developing advanced situational awareness capabilities to identify traffic patterns [13] and critical network anomalies. The team employed a range of anomaly detection techniques, including statistical methods, machine learning models such as Isolation Forest, One-Class SVM and Local Outlier Factor, and deep learning approaches using Long Short-Term Memory (LSTM) networks. These methods, which were trained with synthetic and real traffic data, showed high accuracy in detecting deviations. The team also refined data ingestion and preprocessing by collecting data from Inductive Loop Detectors and mobile network sources and applying advanced cleaning techniques and feature engineering to improve model performance. Predictive models were developed for both anomaly detection and demand forecasting, with LSTM networks proving effective in predicting future transport demand based on historical data.

It is expected that the results of these activities will improve the efficiency, resilience and effectiveness of future mobility systems by utilising the capabilities of CCAM technologies.

## 5 CONCLUSIONS

This paper presents the outline of the Horizon Europe project CONDUCTOR, which explores innovations in traffic and fleet management to optimise the transportation of passengers and goods. The project achievements are the outcome of a comprehensive collection of recommendations, in which the needs of various users and stakeholders were identified and compared with current regulatory requirements. The recommendations led to the development of a conceptual design, comprising several components and their functionalities. Next, the architecture for each pilot was defined and detailed, establishing clear relationships and dependencies between data sources, models and algorithms. Several models were developed and updated, such as for traffic management, fleet management, multimodality, interoperability and multi-resolution simulation. In addition, various data handling solutions for data gathering, fusion and analysis as well as various optimisation techniques such as network load balancing, dynamic optimisation and anomaly detection were designed and developed. These models and algorithms have been integrated and the validation phase has recently started.

**ACKNOWLEDGEMENT**

This work is part of a project funded by the European Union from Horizon Europe research and innovation programme under Grant Agreement No. 101077049 (CONDUCTOR). The authors also acknowledge the financial support of the Slovenian Research and Innovation Agency (core funding No. P2-0098).

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